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TRANSIENTS DUE TO SWITCHING OPERATIONS ON 44-kV, 30-MVAr GROUNDED CAPACITOR BANK (SC1) AT SOUTH MARCH TS

A. Narang

Voltage and current transients were recorded during close-open operations on a Type KSO oil circuit breaker while switching the 44-kV, 30-MVAr grounded capacitor bank (SC1) at South March TS. A maximum overvoltage of 1.6 pu and a maximum inrush current of 8.0 pu were recorded during capacitor switching operations. These are considered representative of the transient magnitudes possible at the station during isolated bank switching on SC1. A number of reignitions and restrikes resulted on opening the capacitor breaker, but these are to be expected for this type of breaker in this application. While breaker performance was similar to that observed for this type of breaker at other capacitor installations, an uncertainty remains concerning the permissible arcing duration on breaker opening which should be resolved. No specific cause has been identified on the basis of these results, for recent failures of apparatus associated with capacitor banks at the station.

1. INTRODUCTION

Several equipment failures involving the two 44-kV capacitor banks at South March TS occurred over an interval of a few months in 1986. These have included the failure of capacitor breakers on SC1 on two occasions; first in April 1986 and subsequently in May 1986 on a replacement oil circuit breaker (Type KSO). However, neither failure occurred while switching the capacitor bank. Rather, the first breaker failed more than 4 hours after the previous opening operation, and the replacement breaker failed phase-to-phase in oil, several seconds after it had been closed to energize SC1 for the second time. Inspection of the breaker by Station Maintenance showed no apparent mechanical damage. Therefore, following clean-up and replacement of the oil, the breaker was declared available for service.

In addition to the breaker failures, about 70 capacitor units failed on SC2 (44-kV, 20-MVAr ungrounded and 10-MVAr grounded) in April 1986, while the capacitor bank was in service (ie not being switched).

In view of these recent failures, we agreed to record the first few switching operations on SC1 with a view towards identifying any unusual phenomena/1,2/. This report presents an assessment of the results of close-open switching operations performed on SC1 on November 5, 1986.

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2. ELECTRICAL ARRANGEMENT

A single-line diagram of the switchyard at South March TS is shown in Figure 1. The SC1 capacitor bank is a double-wye connected, grounded bank with CT s connected in the neutral of each wye for sensing neutral (unbalance) current. The capacitor is switched using a 46-kV oil circuit breaker (Type KSO) equipped with 150 Ω per interrupter (300 Ω per phase) arc-shunting resistors. A 1-mH reactor is also installed in series with SC1 to limit inrush currents during back-to-back switching involving SC2. At the time of these tests, however, SC2 was not available for service, therefore no back-to-back switching operations were conducted.

Further details concerning equipment specifications are included in Appendix A.

3. INSTRUMENTATION

Phase-to-ground bus voltages and capacitor inrush currents were recorded using two NICOLET 4-channel digital oscilloscopes (Model 4094A). Digitizing rates of up to 20 μs per sample were used to record voltage and current transients. Bus voltages were monitored using existing 3ϕ magnetic potential transformers, and capacitor currents using 1600:5-A breaker CT s.

All capacitor switching operations were performed manually by the regional staff at South March TS. Consequently no control was exercised over the point-on-wave at which closing and opening operations were initiated. Bus voltage was regulated manually by station operators after each switching operation, by adjusting taps on transformers T1 and T2.

4. RESULTS OF SWITCHING OPERATIONS

A total of five close-open switching operations were performed on the capacitor breaker. Average bus voltage was 45 kV prior to closing the capacitor breaker, and 46 kV prior to opening.

On closing, current was initiated on the main contacts about 2 (60-Hz) cycles after current initiation through the pre-insertion resistors. The maximum recorded phase-to-ground transient overvoltage was 1.4 pu, and peak inrush current reached 6.9 pu (3.8 kA). Figure 2 displays the recorded voltage and current transients on one closing operation.

On opening, the breaker tended to incur reignitions on virtually every operation, while single restrikes occurred on two occasions. Some switching operations resulted in more than one reignition on the same phase (Table I). Reignitions even occurred on the resistor contacts, which is unusual in that such occurrences have not been observed in previous tests on similar breakers. On the other hand, the instrumentation used previously did not have the resolution necessary to detect reignitions on resistor contacts. In any event, there is no reason to believe that such occurrences are a cause for concern.

A maximum transient overvoltage of 1.4 pu was recorded following a restrike on opening, and peak inrush current reached 8.0 pu (4.4 kA). Figure 3 displays the transients recorded on one breaker opening operation. In this instance, reignitions occurred on the main contacts on Rϕ and Bϕ, and on resistor contacts on all three phases.

Subsequent to the planned capacitor switching operations on November 5, 1987, instrumentation was left connected at the station in unattended mode, in order to monitor continuously and record any voltage transients appearing at the 44-kV bus. A total of twenty events were recorded over a duration of 5 days from November 5 to November 10, 1987. The highest overvoltage recorded

was about 1.6 pu due to a capacitor breaker closing operation on November 9, 1987 (at 07:05 hours). Of the remaining 19 recorded events, those not readily identifiable as capacitor switching operations were of no consequence.

5. ASSESSMENT

There is no evidence of unusual voltage or current transients being generated during switching operations on SC1 at South March TS. The transients produced are entirely predictable, and are no different in nature than those encountered at other similar capacitor installations. Breaker opening operations are frequently accompanied by reignitions, and occasionally by restrikes, as is to be expected in this application.

One measure of breaker operating performance is the duration of contact-arcing on an opening operation. This was determined for the SC1 capacitor breaker for each opening operation as follows. Timing tests conducted prior to the capacitor switching operations (Appendix A) showed that the time from initiation of an opening operation (including operating times for interposing relays) to contact-part on the arc-shunting resistors was about 76 ms, or 4.6 (60-Hz) cycles. During capacitor switching operations, the time from trip initiation to final current interruption on the resistor contacts was as noted in Table I. The difference between 4.6 cycles and these tabulated times is the arcing duration on resistor contacts. The maximum arcing time occurred on Wϕ in Test #5, reaching 31 ms, or 1.9 (60-Hz) cycles.

To assess its significance, this duration should be compared with the period of contact travel from contact-part (resistor contacts) to emergence of the moving contacts outside the interrupter, which is estimated to be about 2 (60-Hz) cycles[1] for this breaker. At the end of this period, the moving contacts are completely outside the interrupter. If the contacts are still arcing, the arc is in bulk oil, outside the confines of the interrupter. Whether the breaker is capable of interrupting satisfactorily under these conditions is not known. Guidance should be sought from the breaker manufacturer on whether such eventuality is acceptable. Our concern with the arc remaining established even after the moving contacts have emerged from the interrupter is that the arc could wander and cause a phase-to-phase or a phase-to-ground fault within the breaker. On this basis, the performance of the capacitor breaker could be viewed as being marginal.

On the other hand if breaker performance is assessed on the basis of past experience with similar breakers, there would not appear to be a cause for concern. For instance, capacitor switching tests carried out at R.L. Dobbin TS showed that the duration of resistor current on opening (which comprises the time from arc extinction on the main contacts to final interruption on resistor contacts) was 5 (60-Hz) cycles for one KSO breaker/3/, and 3 to 3-1/2 cycles for another/4/. In comparison, this duration was consistently less than 4 (60-Hz) cycles at South March TS.

In the absence of further details concerning breakers at South March TS and R.L. Dobbin TS, we are unable to arrive at a firm conclusion regarding breaker performance. Past experience suggests that KSO breakers should be capable of this duty since they have been operating successfully at similar installations for a number of years. However, the uncertainty noted above concerning permissible arcing duration on breaker opening cannot be overlooked. Prolonged contact arcing on opening could lead to an internal fault on the breaker. Consequently, this issue

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1. Based on specified contact opening speed of 2.7 m/s, and an estimated resistor arcing-chamber length of 9 cm. A contact opening speed of 2.8 m/s was determined from an analyzer chart recording (dated May 1986) for this breaker.

should be resolved at the earliest possible time in consultation with the breaker manufacturer. Other than this uncertainty, there was no indication that a mechanism exists which could produce unusually high transient voltages at South March TS while switching the SC1 capacitor bank.

Transients produced upon switching the SC2 capacitor bank at South March TS could not be monitored because the bank was still being refurbished following the April 1986 failure. However our analysis indicates that switching operations on this bank are likely to produce transients higher in magnitude/5/ than those recorded for SC1. This is because SC2 has a composite grounding arrangement (20 MVAr ungrounded, 10 MVAr grounded), while SC1 is fully grounded. Analysis shows that breaker recovery voltages are higher with composite neutral-grounding arrangement. As a consequence, not only are reignitions and restrikes likely to occur more frequently, but on occasion, restrikes will be more severe. This inevitably produces higher magnitudes of voltage and current transients. While we foresee no immediate hazard, the implication is that this neutral grounding arrangement accentuates problems inherent in the operation of grounded capacitor banks. Unfortunately no comparative data is available concerning the transient performance of the two types of capacitor installations, since we have had no prior occasion to monitor transients on a bank with a composite neutral-grounding arrangement.

5. SUMMARY

(a) A concern has been identified regarding the duration of contact-arcing on the capacitor breaker during opening operations. It is suggested that the breaker manufacturer be consulted to determine if the breaker is performing as expected.

(b) Maximum phase-to-ground transient overvoltage while switching SC1 reached 1.4 pu during on-site tests, and 1.6 pu during continuous monitoring of bus voltages over a subsequent five-day period.

(c) Peak inrush current reached 6.9 pu while energizing SC1 with SC2 not in service. During breaker opening, a maximum inrush current of 8.0 pu resulted due to a restrike on one breaker pole. No switching operations were performed with SC2 energized because this bank was not available for service at the time of these tests.

(d) Reignitions occurred on the main contacts as well as on the resistor contacts on virtually every breaker opening operation. Single restrikes resulted on the main contacts on two of the five opening operations. However, these are to be expected, and are considered normal for this type of breaker in this application.

(e) On the basis of the transients recorded while switching capacitor bank SC1, and the continuous monitoring carried out over a five-day period, no mechanisms have been identified to account for the recent history of equipment failures at South March TS.

(f) Analysis indicates that switching operations on SC2 are likely to produce higher magnitudes of voltage and current transients than those produced on switching SC1.

6. RECOMMENDATIONS

In view of the possible adverse consequences associated with prolonged arcing on breaker opening, it is advisable that this issue be resolved in consultation with the breaker manufacturer.

Approved:

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2. A.F. Baljet. Memo to J.S. Hartill, "Monitoring Capacitor Switching Transients on SC1 at South March TS (PRF No. 18-104-202-33)", November 7, 1986.

3. Erven, C.C. "Shunt Capacitor Switching Transients on 44 kV, 30 MVAr, Wye Grounded Banks at R.L. Dobbin TS". Research Division Report #75-498-H. December 1, 1975.

4. Narang, A. "Capacitor Switching Tests at Dobbin TS on 44 kV, 30 MVAr Grounded-Wye Bank with 1 mH Series Reactors". Research Division Report #83-8-K. January 18, 1983.

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APPENDIX A

EQUIPMENT SPECIFICATIONS

A.1 Circuit Breaker 59SC1Q:

Canadian General Electric Type KSO-46-150 (Oil circuit breaker; Serial No. 63145)

Rated Voltage	46 kV
Maximum Design Voltage	48.3 kV
Continuous current	1200 A
Interruption Rating at Rated Voltage	19 kA (1500 MVA)
Maximum Interruption Rating	22 kA

Arc-shunting resistors: 150 Ω per interrupter, 300 Ω per pole

Timing - From Analyzer Charts:

Trip to start of motion	2.4 (60-Hz) cycles
Trip to contact part	3.2 (60-Hz) cycles
Trip to fully open	15.2 (60-Hz) cycles
Close to start of motion	9.7 (60-Hz) cycles
Close to contact touch	25.8 (60-Hz) cycles
Close to latched	26.2 (60-Hz) cycles

Timing - From on-site tests performed by Electrical Research

Trip initiation to main contact part	43 ms (2.6 60-Hz cycles)
Trip initiation to resistor contact part	76 ms (4.6 60-Hz cycles)
Close initiation to resistor contact touch	350 ms (21.6 60-Hz cycles)
Close initiation to main contact touch	390 ms (23.4 60-Hz cycles)

A.2 Capacitor Bank SC1:

Westinghouse Co. Ltd
Rated voltage 46 kV
Total capacity 31.2 MVAr
13.2 kV, 200 kVAr capacitor units (3.14 μF)
156 capacitor units; 2 series groups per wye, 13 parallel per group; double-wye per phase.
WEMCOL 1 dielectric fluid
15 MΩ discharge resistors

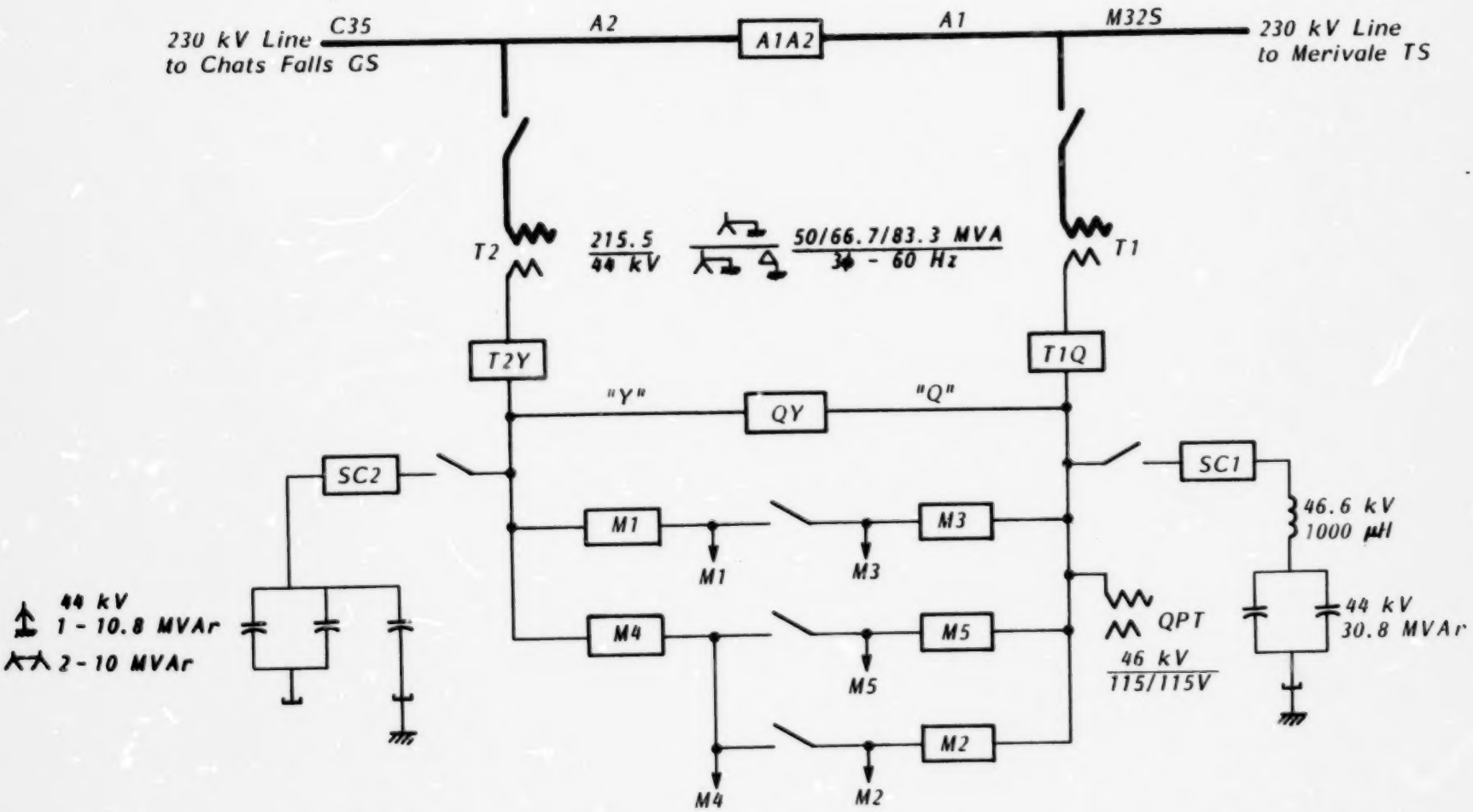

FIGURE 1

SINGLE-LINE SCHEMATIC OF RELEVANT PORTION
OF SOUTH MARCH TS

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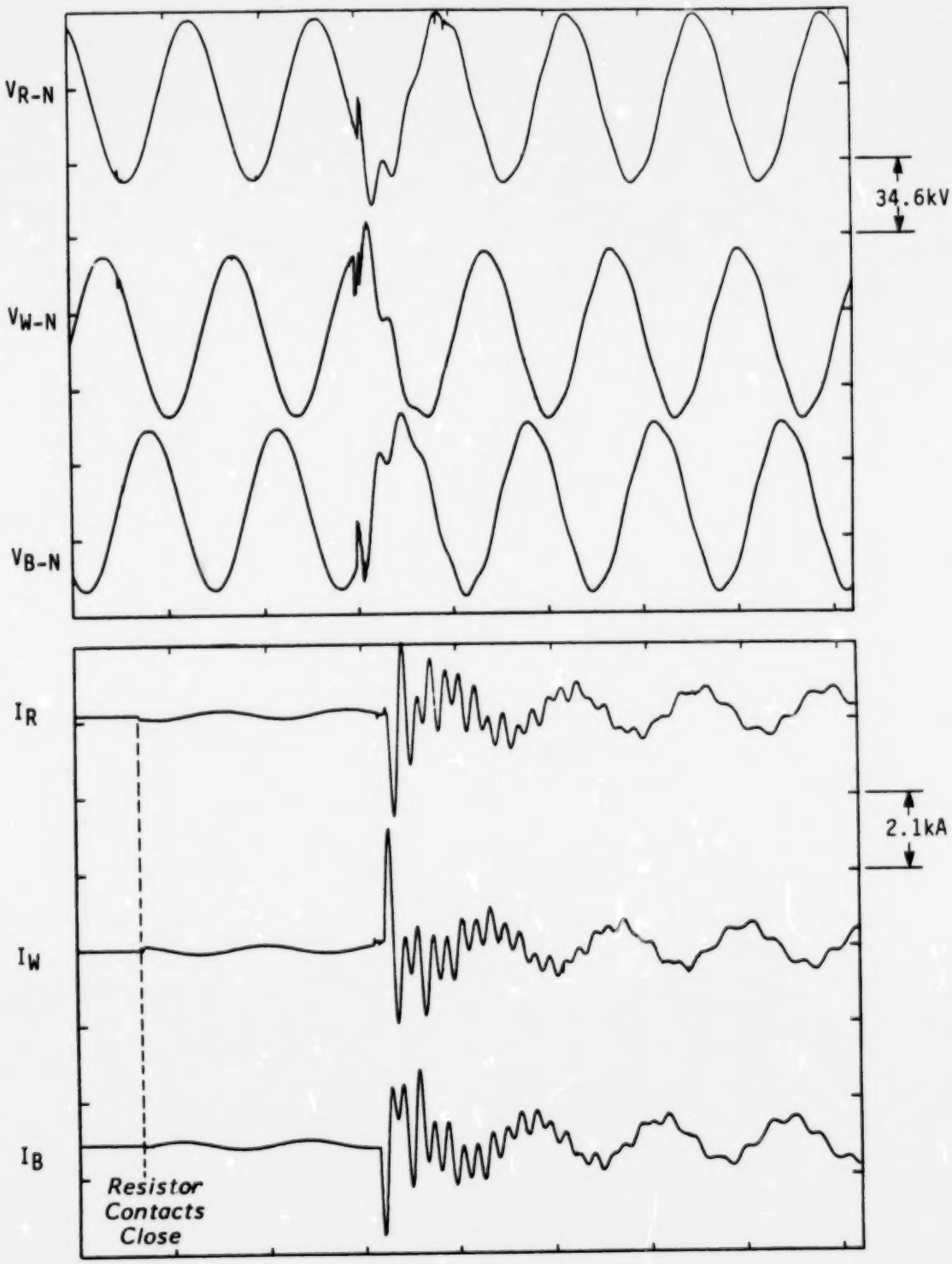

FIGURE 2

VOLTAGE AND CURRENT TRANSIENTS DUE TO ENERGIZING 44 kV, 30 MVAr CAPACITOR (SCI) AT SOUTH MARCH TS (TEST #1C)

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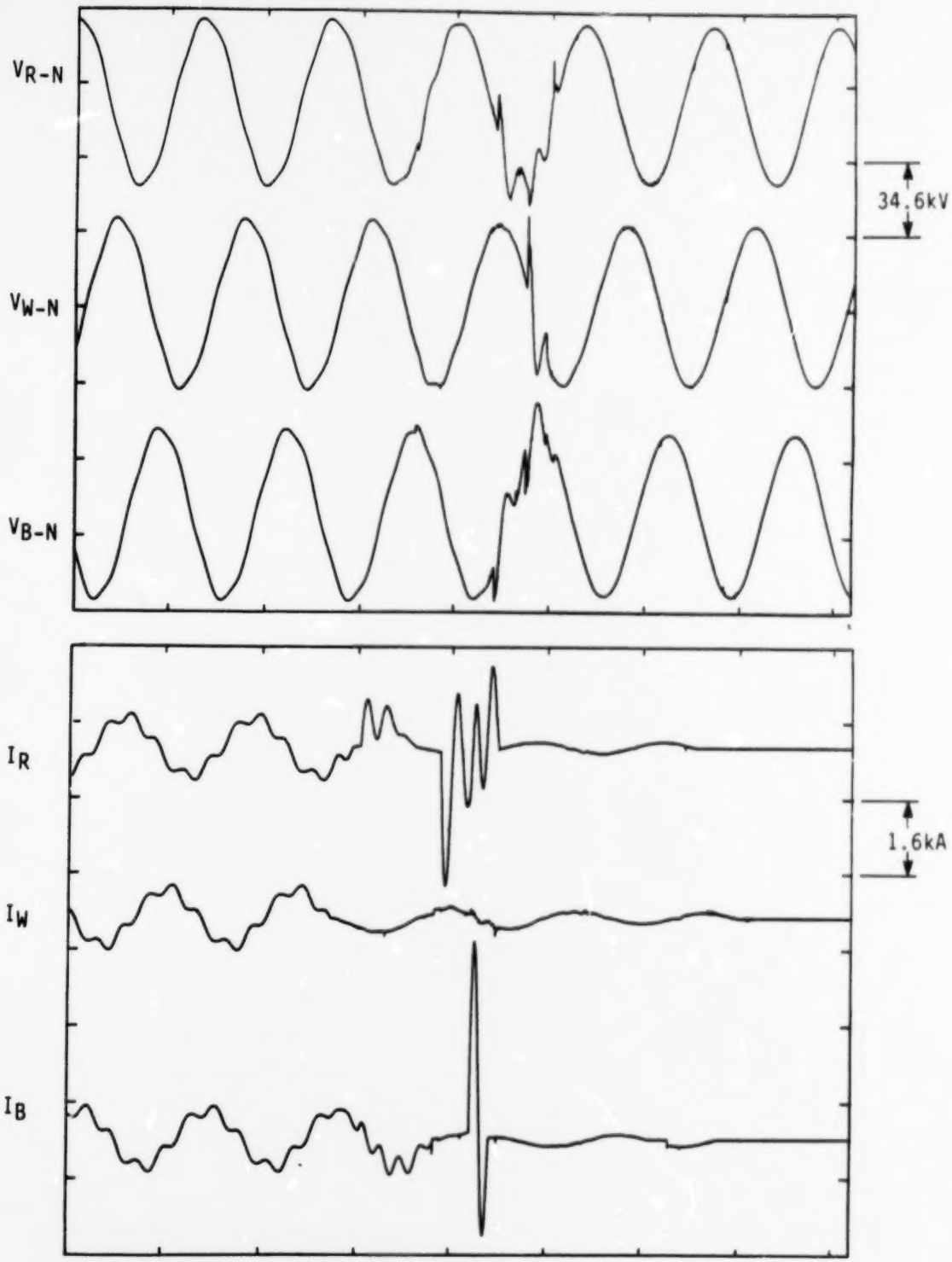

FIGURE 3

VOLTAGE AND CURRENT TRANSIENTS DUE TO REIGNITIONS ON CAPACITOR BREAKER SC1Q AT SOUTH MARCH TS ON AN OPENING OPERATION (TEST #2T)

174461-RD

TABLE I

PERFORMANCE OF TYPE 'KSO' 46 kV OIL CIRCUIT BREAKER WHILE INTERRUPTING SC1 (46 kV, 31.2 MVAr) CAPACITOR CURRENT AT SOUTH MARCH TS

Test #	Time to Initial Interruption on Main Contacts [60-Hz cycles]			Time to Final interruption on Resistor contacts [60-Hz cycles]			Reignitions (r) or Restrikes(R) on Main Contacts			Reignitions (r) on Resistor Contacts			Switching Configuration
	RØ	WØ	BØ	RØ	WØ	BØ	RØ	WØ	BØ	RØ	WØ	BØ	
1	2.8	2.6	2.6	6.0	5.8	5.6	1r	-	1r	1r	1r	-	T1Q,T2Y,QY,M1 & M4 Closed M2, M3, M5 Open
2	2.9	2.7	3.6	5.6	5.9	5.8	2r	-	1r	1r	2r	1r	" "
3	3.9	3.4	2.8	5.8	5.7	5.5	-	1r	1r,1R	1r	1r	1r	" "
4	3.1	2.5	2.9	5.9	6.2	6.1	-	-	1r	1r	2r	2r	Normal operating config. (All 44-kV breakers closed)
5	2.9	3.2	3.1	6.1	6.4	5.8	1r	1R	1r	2r	1r	1r	" "

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